Work Session # 1: Measurements and Significant Figures

Introduction

Measurements are made using tools. The tool can be as simple as a ruler or as complex as the Hubble Space Telescope. It is typical that finer measurements require more expensive tools to make the measurement. For example, we have two types of electronic balances in the laboratory. One is a **top-loading balance**, and the other is an **analytical balance**. The top-loading balance is capable of measuring to the nearest 0.1 g, while the analytical balance measures to the nearest 0.001 g. The first costs approximately $125; the other costs upwards of $1,000.

A general principle when making measurements and recording the results is: **Always record the measurement to the full capacity of the tool used. Never record the measurement with more than or less than the capacity of the tool used.** For example: a penny on the top-loading (decigram) balance in this lab may read 2.4 g on the display, whereas the same penny on the analytical (milligram) balance may read 2.413 g. If the display reads to the milligram, **then record the mass with the appropriate *level of precision* and include all of the decimals shown.** If the balance shows 2.400 in the display window, then record 2.400 g on the data sheet. The manner in which the data is recorded indicates the accuracy of the tool used to make the measurement. If you record 2.4, it is assumed that the balance used can only give readings to the tenth place. If, in fact, you used a balance that shows 2.400 g, make sure you write 2.400 g as the recorded mass.

It is a common error for students to only record the first few numbers appearing on the display, and then to fill in zeroes when there is a need to record to the nearest milligram. A series of measurements that all end in zero is highly unlikely. Thus, be sure to record the correct values for your results. If you find an error in your data recording, make a note in the margin or remake the measurement. Never change your data.

Balances can give readings different from the true value if they lose their calibration. If the same object is weighed several times on a decigram balance and several times on a decigram balance, the results might look like this:

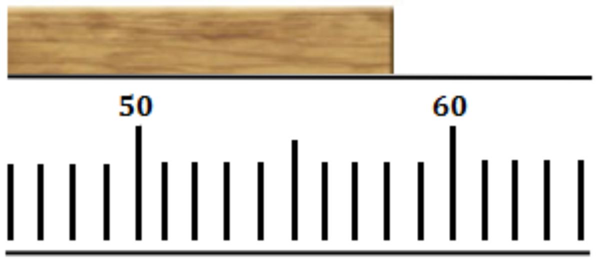
Table 1: Measuring the mass of a penny on four different balances.

Certified mass of the penny used for the measurements below = 2.413 g				
Measurement	**Decigram Balance 1**	**Decigram Balance 2**	**Milligram Balance 1**	**Milligram Balance 2**
1	2.2 g	2.2 g	2.419 g	2.413 g
2	2.1 g	2.3 g	2.411 g	2.412 g
3	2.5 g	2.3 g	2.409 g	2.413 g
4	2.0 g	2.2 g	2.411 g	2.412 g
5	2.6 g	2.2 g	2.408 g	2.413 g
Average =	2.3 g	2.2 g	2.412 g	2.413 g
	Inaccurate and Imprecise	**Inaccurate but Precise**	**Accurate but Imprecise**	**Accurate and Precise**

In Table 1, note how the words *accurate* and *precise* are used. “Accurate” describes whether the measurement is close to the <u>actual</u> (or true) value. “Precise” refers to the <u>reproducibility</u> of a measurement. [NOTE: The terms ‘accurate’ and ‘precision’ are also used to describe the quality of an instrument. In this context, an analytical balance is said to have a higher *level of precision* than a top-loading balance because it reads to 0.001 g rather than 0.1 g.]

On the balances in our lab, a digital display provides the quantity that we need to record. However, for many other types of measurements and measurement devices, the user is required to manually read the value. In such instances, one would record all known digits plus one estimated digit. For example, Figure 1 shows a ruler with increments (or divisions) of **1 cm**. The object being measured is between 58 cm and 59 cm long. Our readings of 58 cm or 59 cm are the known digits. We must add an estimated digit, which would approximate the measurement of object to approximately 58.1 cm. If your estimate is 58.2 cm, that is also an acceptable answer.

Figure 1



Scientific Notation

In science, we often work with numeric values that are very large or very small. Thus, to simplify the reporting of such quantities, we use scientific notation - a coefficient and power of 10. We can generalize scientific notation as **a.bcd x 10***ˣ*. The a,b,c, and d are digits, collectively referred to as the coefficient. The power of 10 - represented as 'x' in the example above - is the exponent.

There are two guidelines for expressing a quantity in scientific notation:

1) 1 ≤ coefficient < 10 The coefficient must be greater than or equal to one, but less than ten.
2) The exponent is a whole number; may be positive or negative.

Examples: 2.3×10^5, 8.89×10^5, and 9.99×10^2 are written in proper scientific notation
0.6×10^2, 22.53×10^{-3}, and 10.01×10^2 are not written in proper scientific notation because the coefficient does not lie between 1 and 10. 10.01×10^2 should be expressed as 1.001×10^3.

Significant Figures

In the Introduction of this Work Session, you have learned that there is always some estimation or error involved when making a measurement. On an electronic balance, the last digit will sometimes flicker back and forth between two numbers, and you will need to make your best estimate of the last digit. There are rules for working with numbers obtained from measurements that take this estimation into account and prevent us from making erroneous calculations.

An example of such a calculation is that of the tour guide in Egypt who told visitors that one of the pyramids was 5006 years old. When asked how he knew that, he replied "When I first came to work 6 years ago, I was told that it was 5000 years old!" Of course, his error lies in adding an accurate 6 years to a roughly estimated 5000 years.

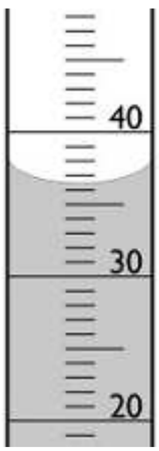
Your textbook gives the rules for significant digits and many examples of their use. Your instructor may provide you with a copy of *Significant Figures: A Quick Review*, which will serve as a handy reference and a brief review of what you have covered in lecture. The expectations for handling significant figures can vary from instructor to instructor, so be sure to ask if you have any additional questions.

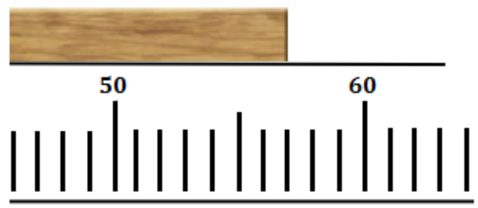
Name: ____ ***Date:*** _______________ ***Grade*** ___

Work Session #1: Measurements and Significant Figures

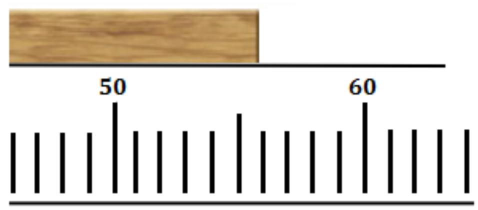
All questions below must be answered during the lab. Show all work and be sure to include units. Express all answers to the correct number of significant figures.

Q1. What would you record for the following measurements? Write in the blank space.



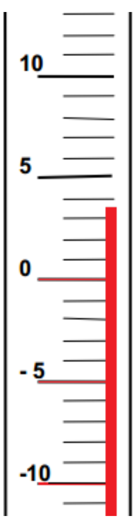


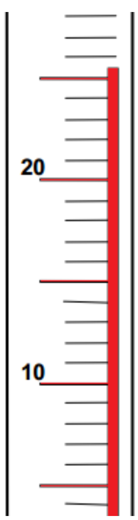
____________cm

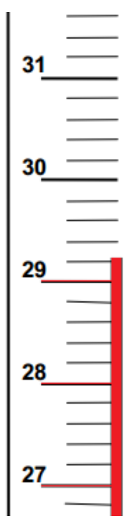


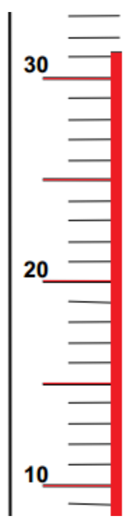
____________cm

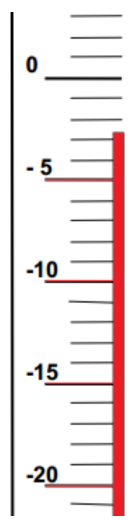
_____________mL ___________mL

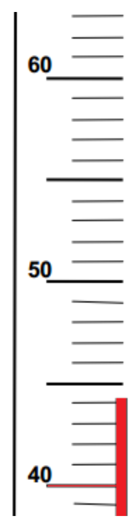












__________ºC __________ºC _________ºC _________ºC ________ºC _________ºC

Q2. Express the following results in proper scientific notation.

Result in Standard Notation	**Result in Scientific Notation**
621.0 g	**6.210×10^2 g**
1583 s	
724 g	
16432 cm	
3,456,000 s	
0.007 mi	
0.000135 nm	
0.08 kg	
0.0009462 cm	
55000 mi	
0.00014 s	
497 m	
10,003 s	
0.89	

Q3. How many significant figures are in each of the following numbers?

Result	**# of Significant Figures**
0.031 cm	2 sf
45.8736 mg	
0.00239 mL	
48,000 in	
93.00 m	
3.982×10^6 m	
1.70×10^{-4} mm	
0.00590 L	
1.00040 km	
4.00000 g	
3800 m	
23000 ± 10 m	

Q4. Round each of the following numbers to 3 significant figures. Do not change their values (that is, if a number is in the thousands before rounding, it will be in the thousands after rounding).

Result	**Rounded to 3 Significant Figures**
98715 mL	98700 mL
1367 m	
0.0037421 km	
1.5587 g	
12.85 L	
1.6683 x 10^{-4} m	
1.632257 cm	

Q5. Perform each of the following indicated operations and give the answer to the proper number of significant digits. Watch the order of operation involved in the same problem. When adding or subtracting numbers written in scientific notation, it often helps to rewrite the numbers so each one has the same index (that is, power of ten). For example, to add 3.42 x 10^{-3} and 5.223 x 10^{-4}, first rewrite the second number as 0.5223 x 10^{-3}. Remember, if you make the coefficient smaller, you make the power bigger, and vice versa. 0.5223 is smaller than 5.223, and 10^{-3} is bigger than 10^{-4}. When adding or subtracting values, be sure that they have the same units.

Problem	**Calculated Answer with Correct Units**	**Answer with Proper SF and correct units**
32.27 m x 1.54 m =		
3.68 g/0.07925 mL =		
1.750m x 0.0342m =		
0.00957 kg/2.9465 L =		
(3.2650 x 10^{24} m) / (4.85 x 10^{3} s) =		
7.56 mg + 0.153 g =		
10.052 cm - 9.8742 cm =		
(6.75 x 10^{-8} mm) + (5.43 x 10^{-7} mm) =		
0.01953 cm + (7.32 x 10^{-3} m) =		
(8.52 m+ 4.1586m) x (18.73 m+ 153.2 m) =		
(8.32 x 10^{-3} mg)$^{1/2}$ =		
(3.84 x 10^{-2} m)^{3} =		
(0.000738 m−8.3 x 10^{-5} m) / (6.298 x 10^{-8} m) =		
log(22.6) =		
ln(12.55) =		

Q6. The average mass of an M&M© is 0.625 g. What is the mass of 12 M&Ms? Consider the proper number of significant figures.

Q7. What is the Celsius equivalent of –30. °F? Use appropriate number of significant figures.

Q8. Isopropyl alcohol, commonly known as rubbing alcohol, boils at 180°F. What is the boiling point in Kelvin?

Q9. Convert 1555 K into ^{o}F. Express your answer to the nearest degree.

Q10. The elevation of City of Santa Clara is approximately 75 ft. What is the elevation in centimeters?

Q11. A car travels at 50.0 miles per hour. What is the equivalent speed in meters/min? (1.609 km = 1 mile)

Q12. If a rectangle measures 4.00 inches by 5/6 inch, what is its area in square centimeters? (1 in = 2.54 cm)

Q13. Each liter of air has a mass of 1.80 grams. How many liters of air are contained in 2.5 x10^3 kg of air?

Q14. 16.0 grams of food contain 130 calories. How many grams of food would you need in order to consume 2150 calories?

Q15. The speed of light is 3.0×10^8 m/s. How many milliseconds does it take for a light signal from earth to reach and return (round trip) from a satellite that is in orbit 30 miles above the earth? (1.609 km = 1 mile, 1 millisecond = 10^{-3} seconds).